Bluff to Beach: **Sand** sources, sinks, and pathways in far western Lake Superior – implications for the genesis and evolution of Minnesota Point

Lake Superior bluff, Douglas County, WI

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UMD University of Minnesota Duluth Driven to Discover

Goals:

- Present a **source-to-sink** framework for erosion, transport, and deposition of **sand** in the Duluth coastal region
- Provide **scientific insight**—on geologic timescales—to guide long-term (human timescale) **strategic planning**

Expenditure of tens of millions of taxpayer dollars for mitigation of coastal erosion necessitates sound understanding of sediment pathways and rates

Acknowledgments:

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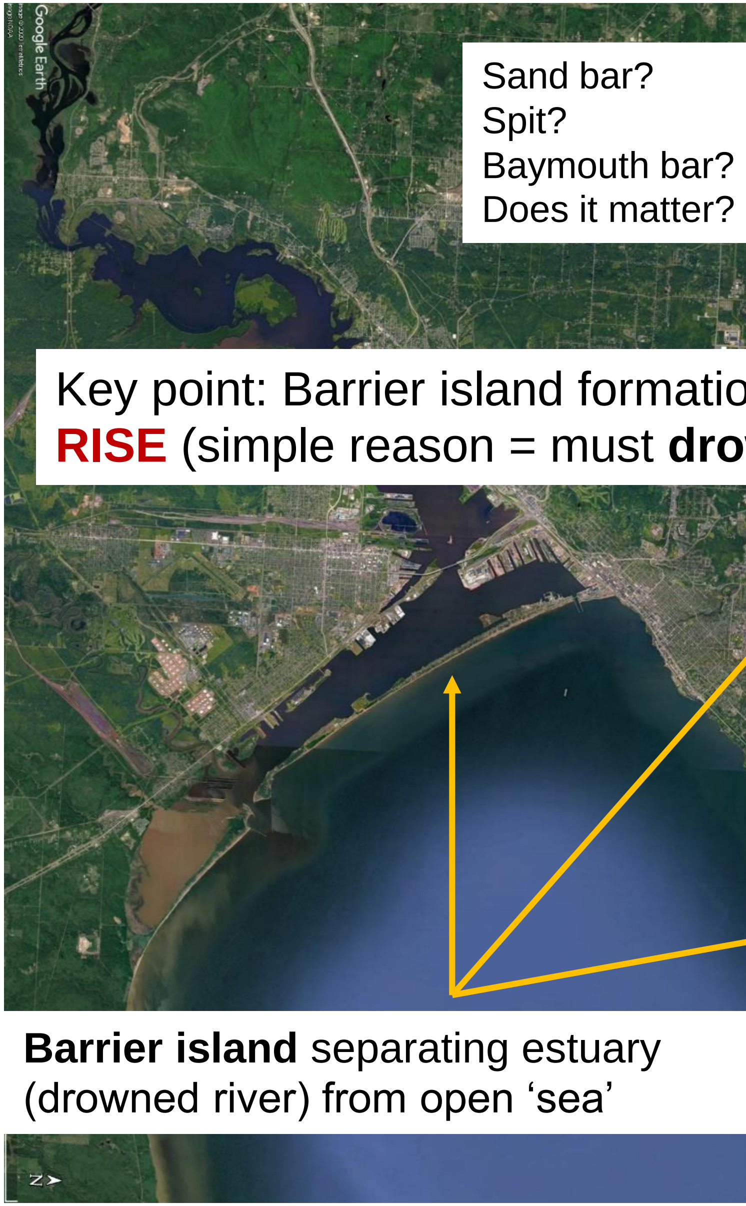
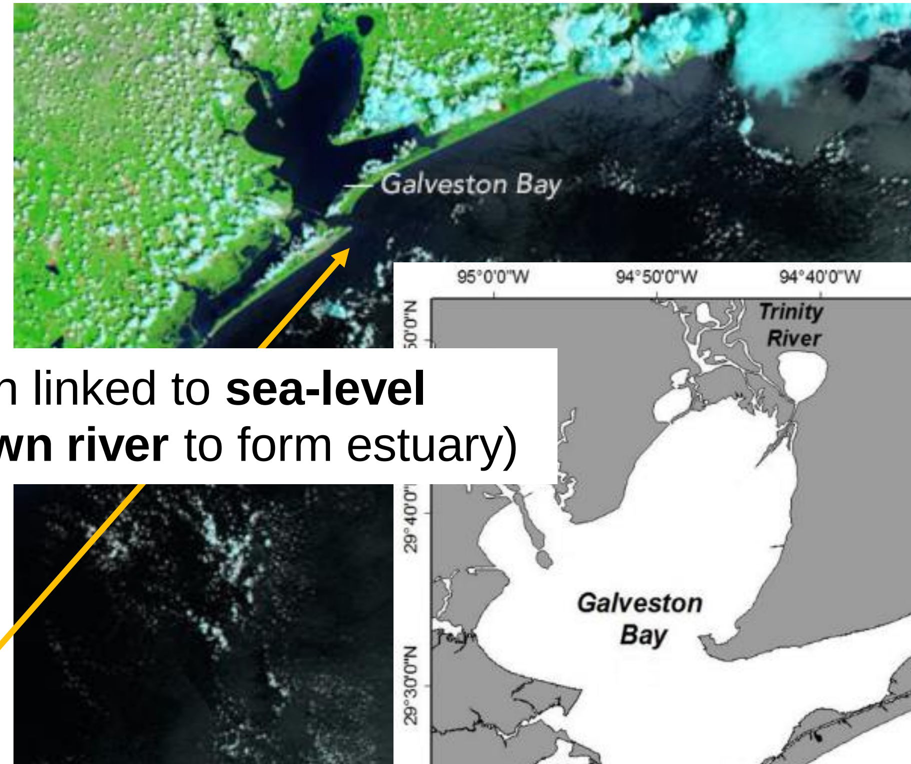
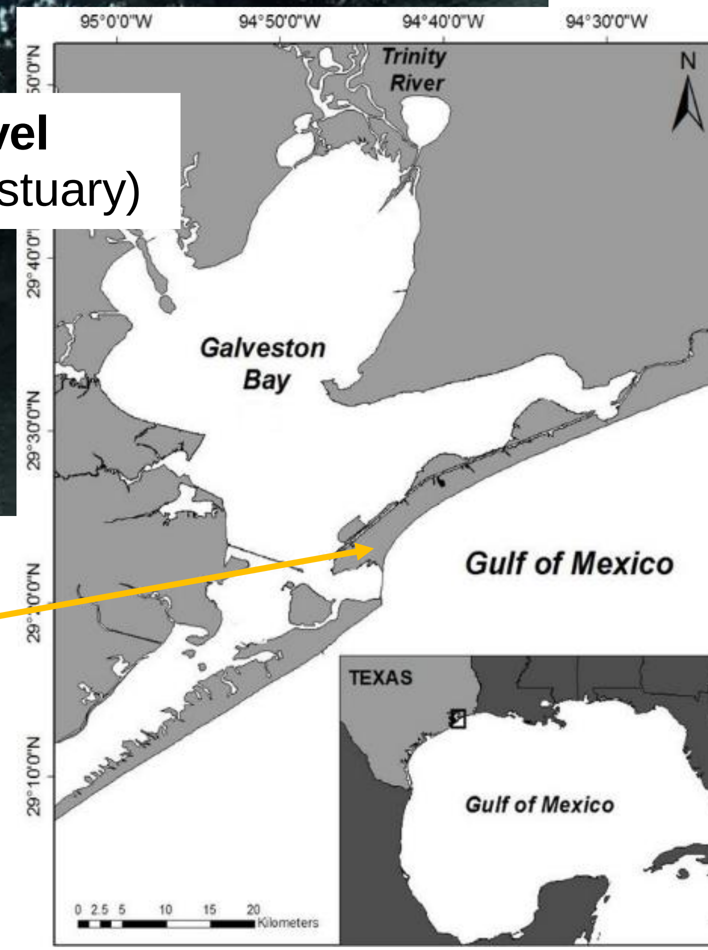
- Andrew Breckenridge (UWS faculty)
- Coastal Erosion Hazard Mapping (CEHM) Task Force colleagues

Comparing apples to apples: What is Minnesota Point?





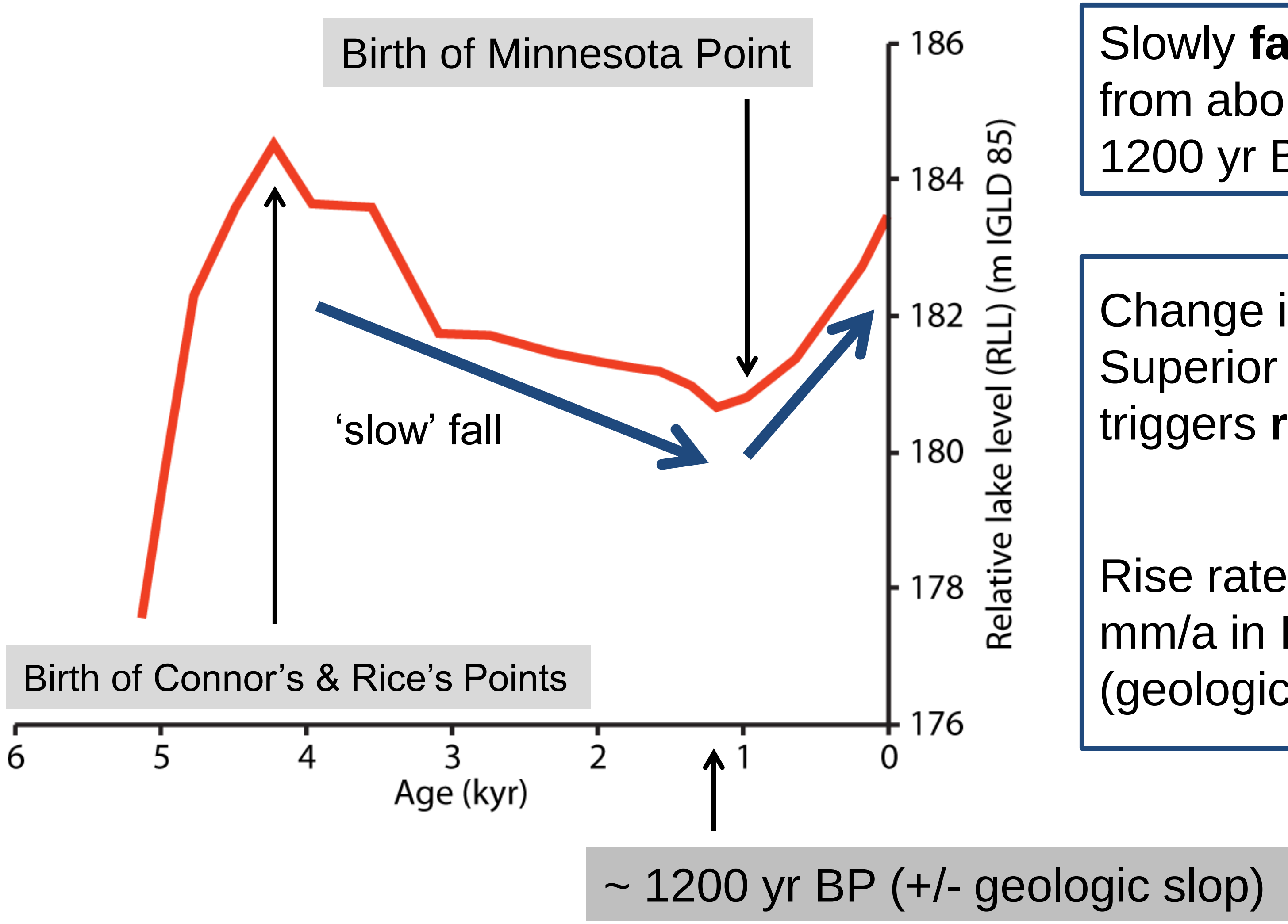


Key point: Barrier island formation linked to **sea-level RISE** (simple reason = must **drown river** to form estuary)

Barrier island separating estuary (drowned river) from open 'sea'

Long-term lake level change in Duluth area

Lake-level curve from Breckenridge et al. (2016), based in part on earlier work by Johnston et al. (2012), Yu et al. (2013), and Mainville and Craymer (2005)



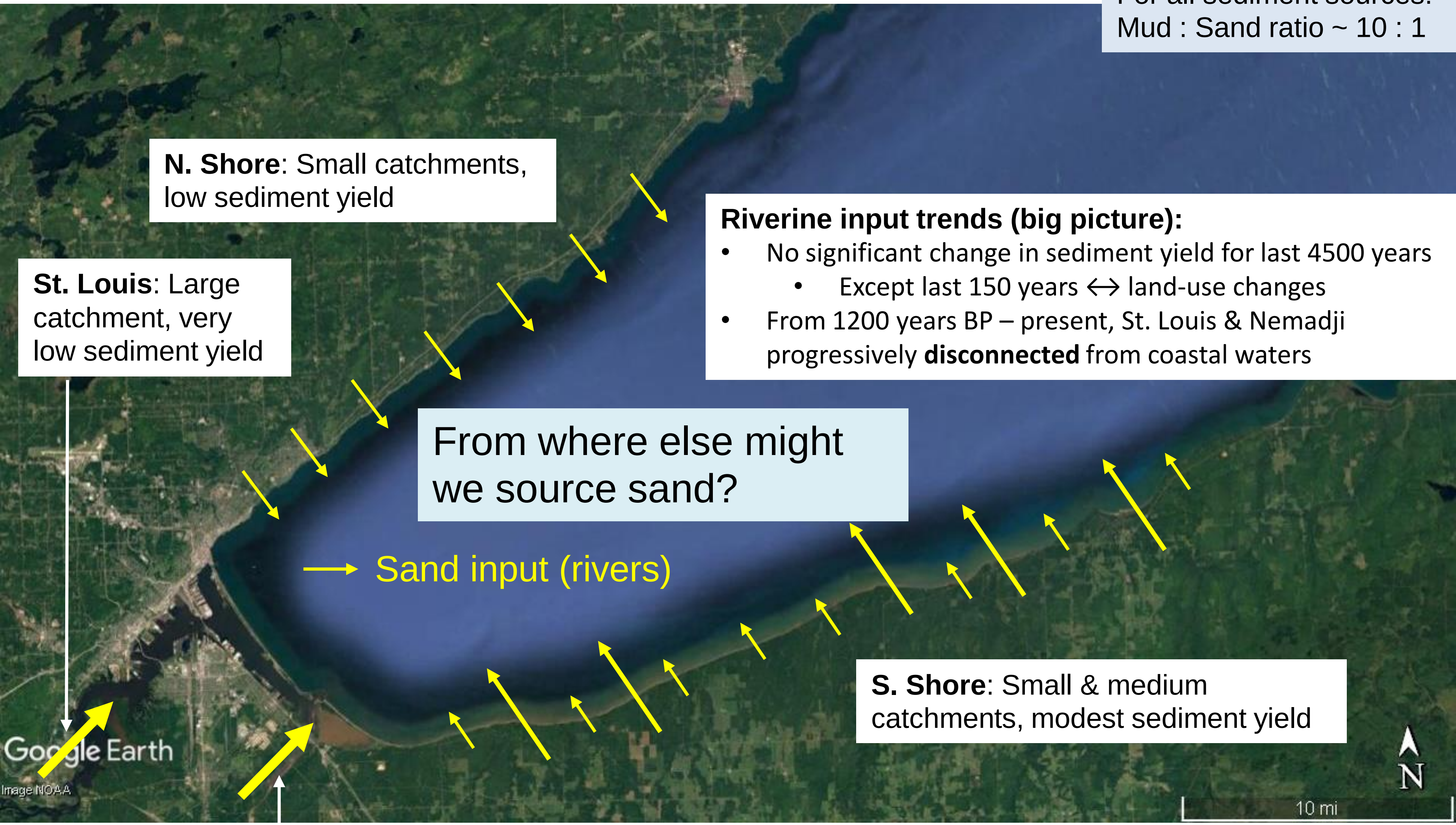
Slowly **falling** lake level from about 4500 yr BP – 1200 yr BP

Change in outlet of Lake Superior @ ~ 1200 yr BP triggers **rise** in lake level

Rise rate ~ 2.5 – 3.0 mm/a in Duluth = FAST (geologically speaking)

Sand **sources**: **Riverine** (fluvial) input

For all sediment sources:
Mud : Sand ratio ~ 10 : 1

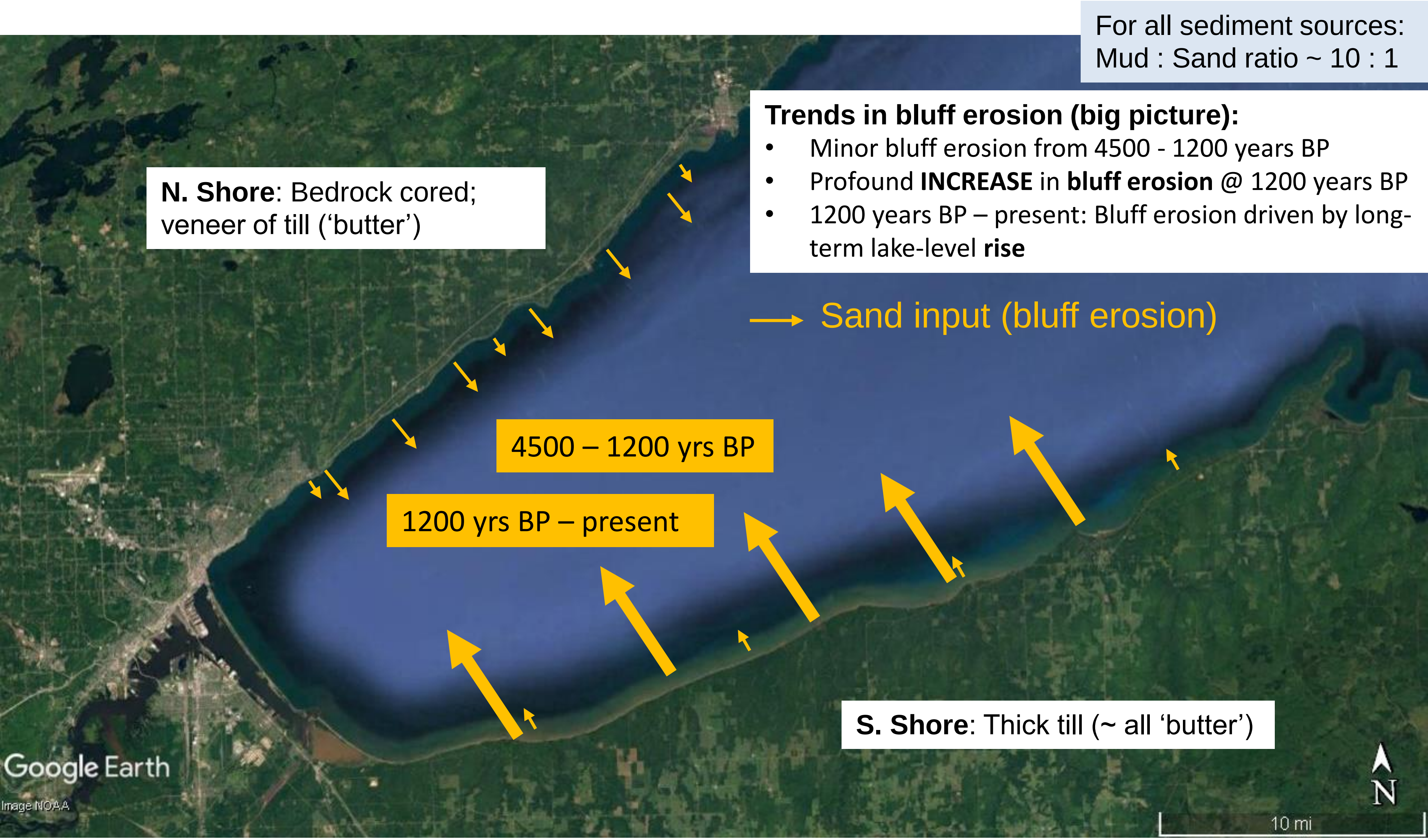


Riverine input trends (big picture):

- No significant change in sediment yield for last 4500 years
  - Except last 150 years ↔ land-use changes
- From 1200 years BP – present, St. Louis & Nemadji progressively **disconnected** from coastal waters

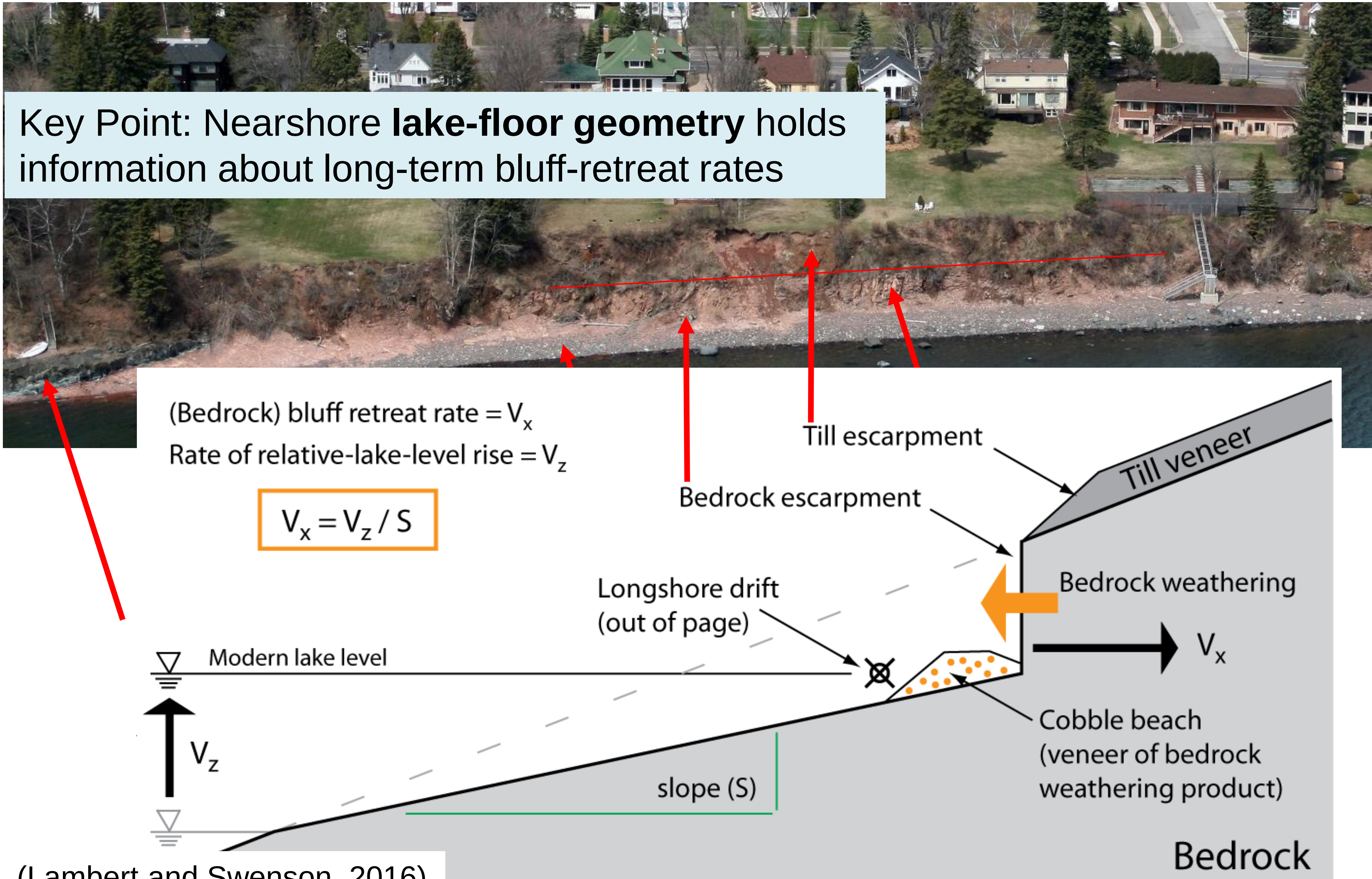
Nemadji: Medium catchment, high sediment yield

Sand **sources**: **Bluff erosion**



Rapid lake-level rise drives **bluff erosion**

Key Point: Nearshore **lake-floor geometry** holds information about long-term bluff-retreat rates



(Lambert and Swenson, 2016)

Long-term (multi-century) **bluff erosion** rates

Label	Unit Name	Offshore Slope	Retreat Rate (cm/a)	Bluff
Mnb-1	Undifferentiated Mafic Lavas	0.049	5.145	N
Mnd	Leif Erikson Park Interflow	0.036	6.979	Y
Mes	Endion Sill	0.064	3.887	N
Mep	Endion granophyre	0.075	3.315	Y
Mnc	Congdon Park Rhyolite	0.060	4.200	Y
Mnn	Northland Basaltic Andesite	0.052	4.823	N
Mnu-1	Mafic Lavas - Lakeside	0.040	6.276	Y
Mne	40th Ave East Icelandite	0.035	7.211	Y
Mnr	42nd Ave East Rhyolite	0.050	4.964	Y
Mnu-2	Mafic Lavas - Lakeside	0.077	3.257	N
Mni-South	Lester Park Icelandite (buffered)	0.068	3.687	N
Mli	Lakeside Intrusion	0.085	2.940	Y
Mnu-3	Mafic Lavas - Lakeside	0.058	4.348	Y
Mni-North	Lester Park Icelandite	0.033	7.606	Y
Mnu-4	Mafic Lavas - Lakeside	0.047	5.271	N
Mna	Amity Creek Diabasic Basalt	0.043	5.811	N
Mnu-5	Mafic Lavas - Lakeside	0.052	4.846	N
Mmd	Lester River Sill	0.065	3.864	N
Mnb-2	North Shore Mafic Lavas	0.043	5.795	N
Srb	Sucker River Basalts	0.057	4.386	
Spd	Stony Point Diabase	0.100	2.500	
Mnb-4	Larsmont Basalts	0.070	3.560	

Bedrock-cored **north**-shore bluff retreat rate ~ **5** cm/yr

Large variability because of mixed lithology, e.g. rhyolite vs. basalt vs. diabase

Lambert and Swenson (2016)

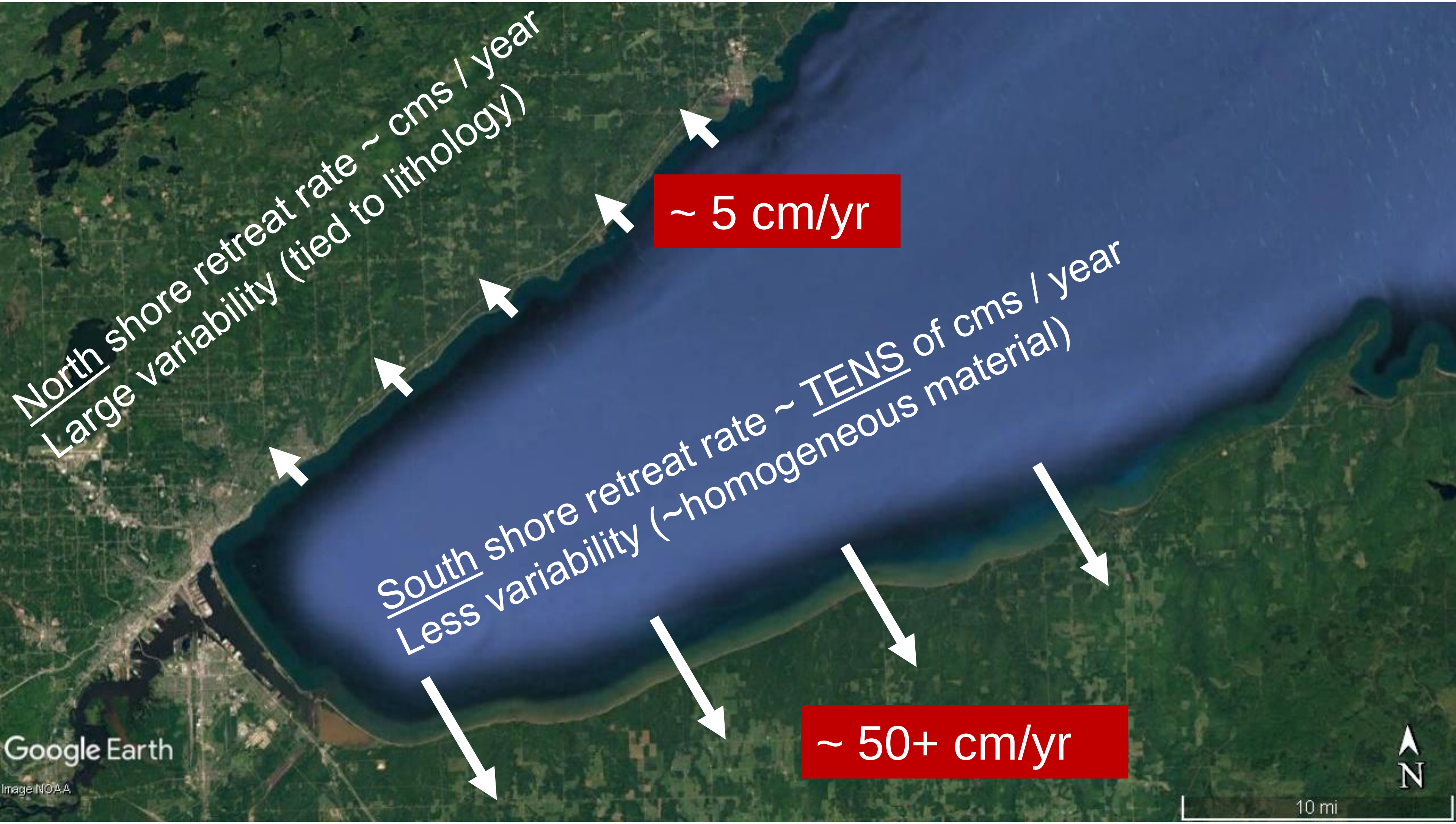
Line	Offshore slope	Retreat Rate (cm/a)
Transect 1	0.0049	51
Transect 2	0.0048	52
Transect 3	0.0039	64
Transect 4	0.0041	61
Transect 5	0.0055	45
Transect 6	0.0061	41
Transect 7	0.0059	42
Transect 8	0.0068	37
Transect 9	0.0077	33

South-shore bluff retreat rate ~ **50** cm/yr

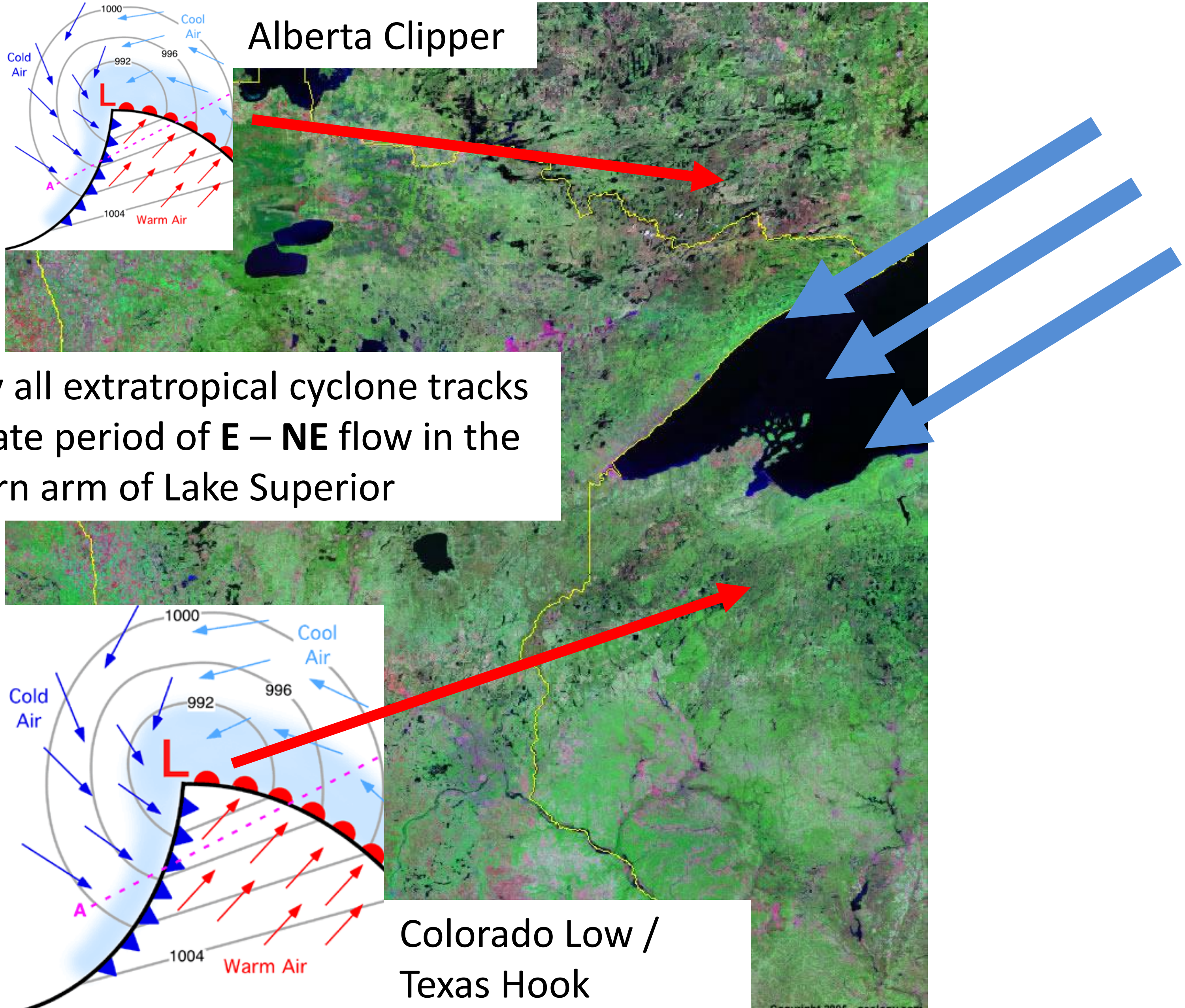
Mechanically weak, unconsolidated till

Less variability -> homogenous till

Bluff retreat is driven by **rise** in lake level from ~1200 yr BP - present



Transport pathways: Sand transported during ‘storms’ (cyclones)

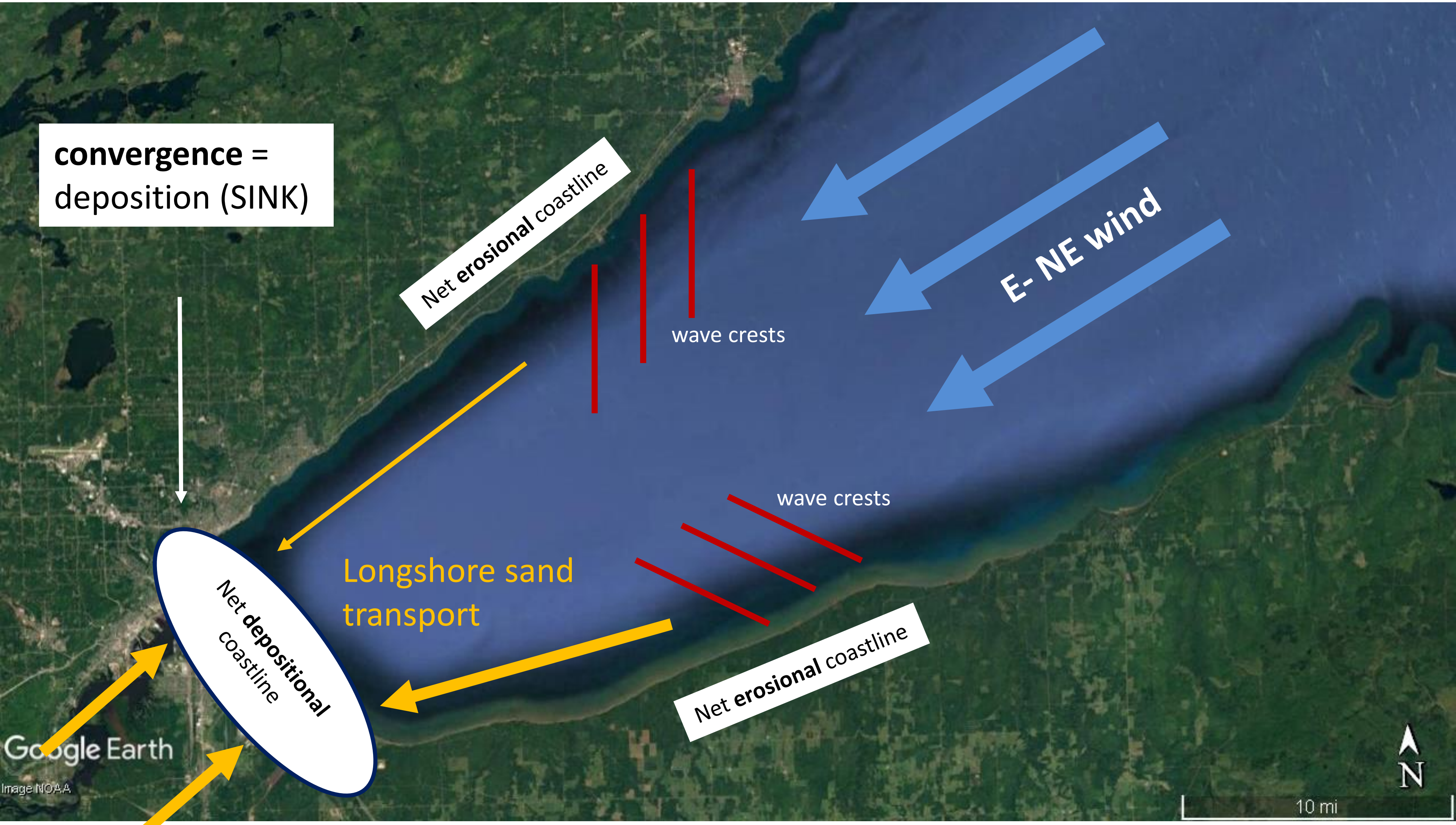


Alberta Clipper

Nearly all extratropical cyclone tracks generate period of **E – NE** flow in the western arm of Lake Superior

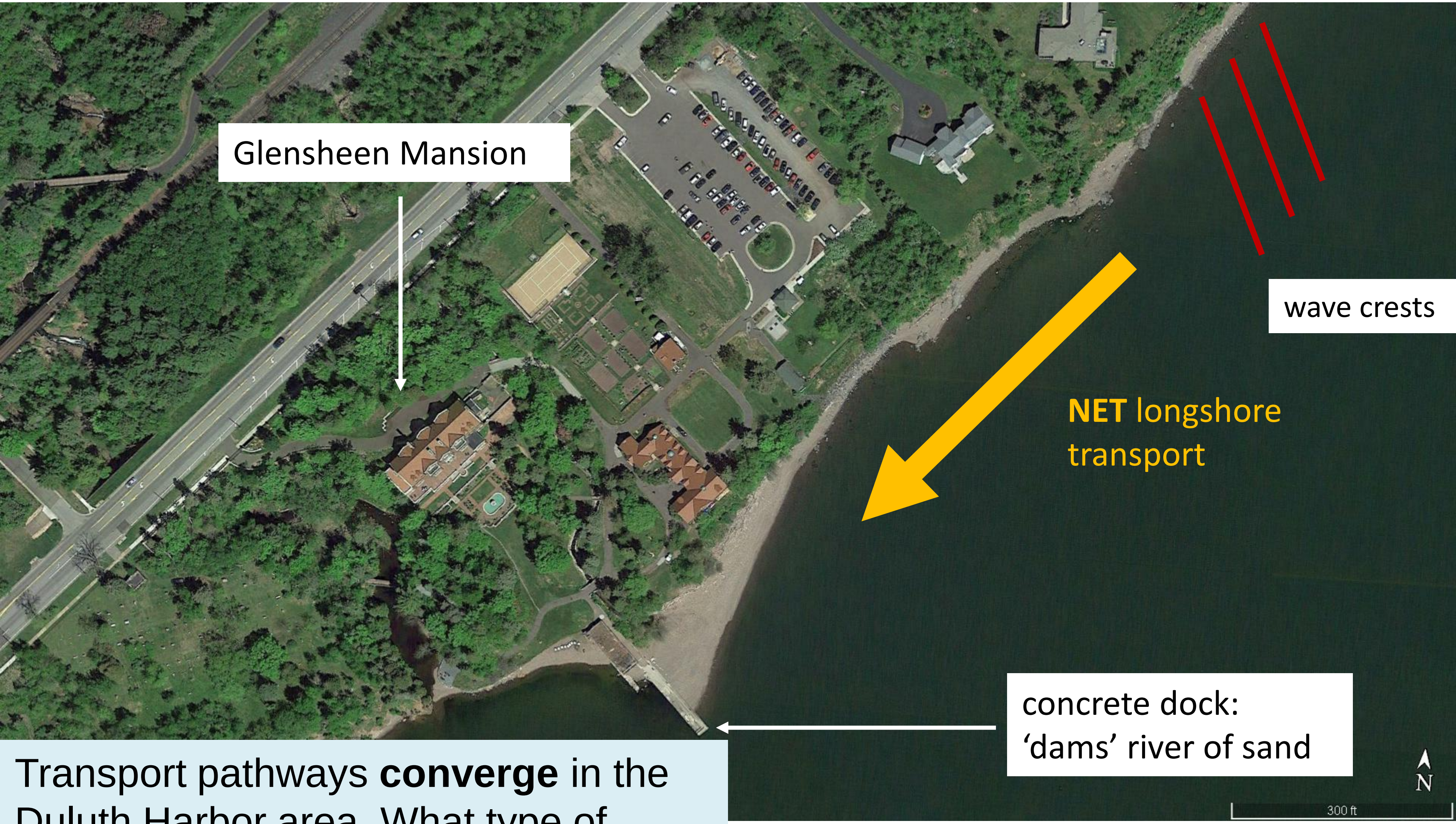
Colorado Low / Texas Hook

Transport pathways: Net **longshore transport** of sand near Duluth



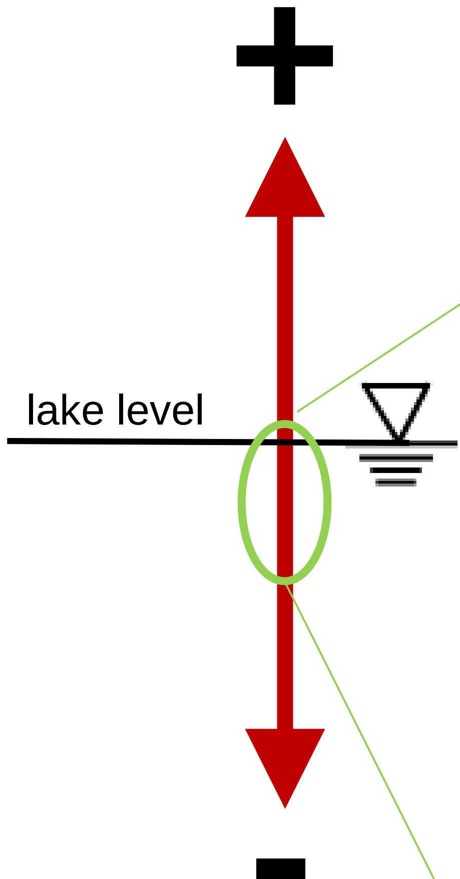
St. Louis & Nemadji Rivers (<u>potentially</u>)
add to net sediment **convergence**

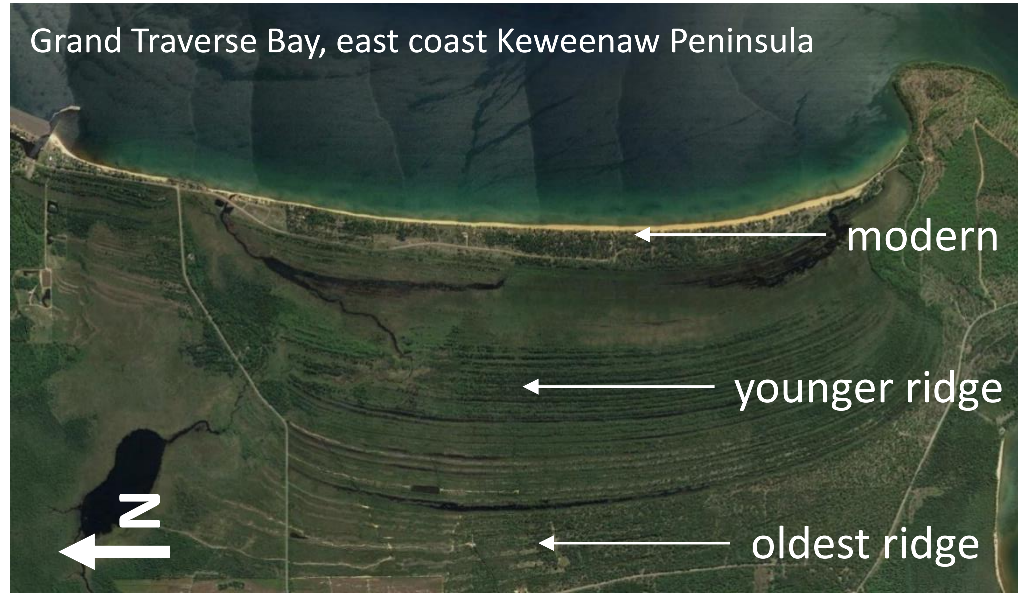
Net **longshore transport** near Duluth

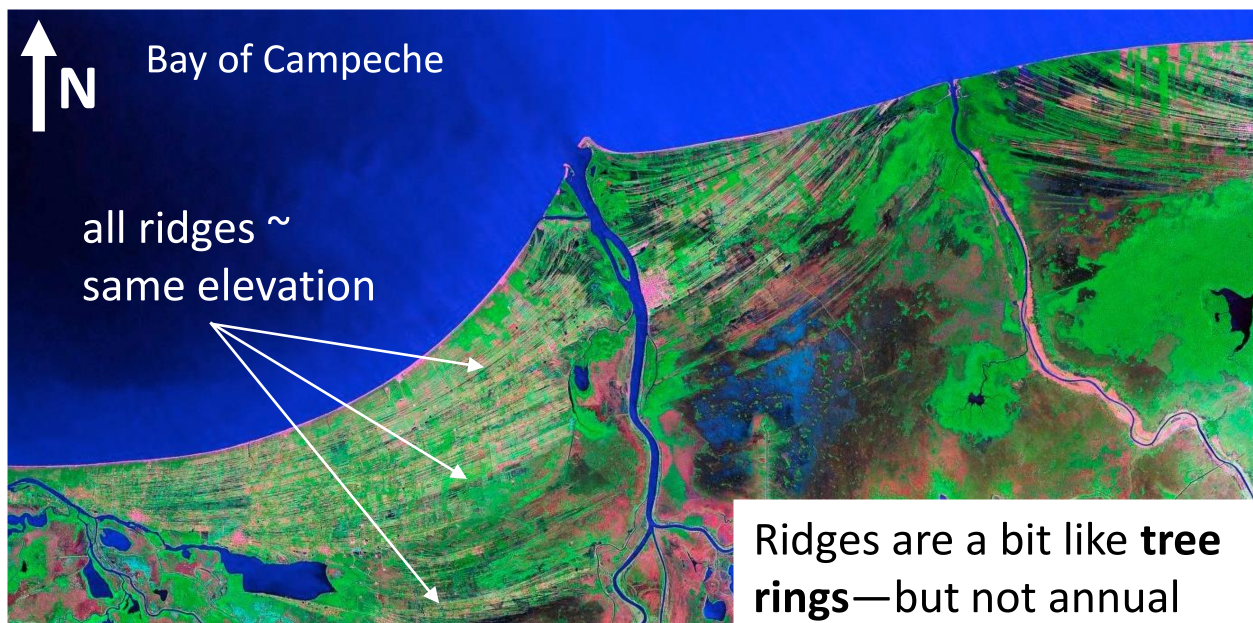


Transport pathways **converge** in the Duluth Harbor area. What type of depositional landform results?

Sand sink: **Depositional landform** flavor depends on **lake-level trend**





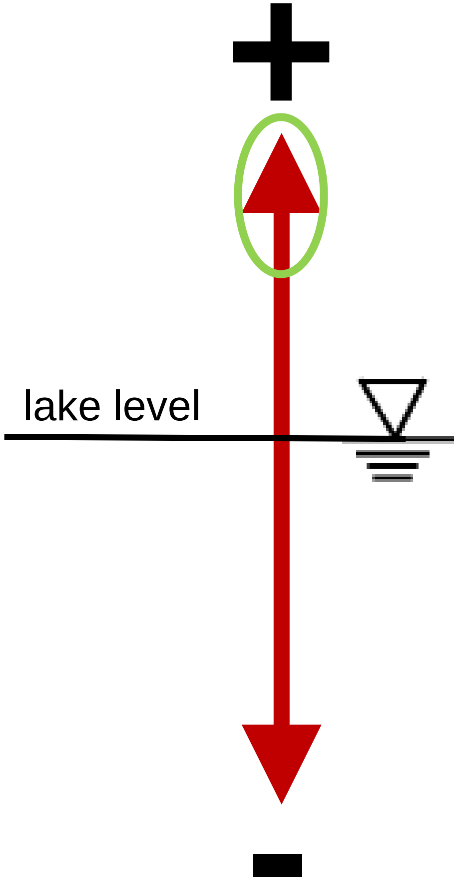


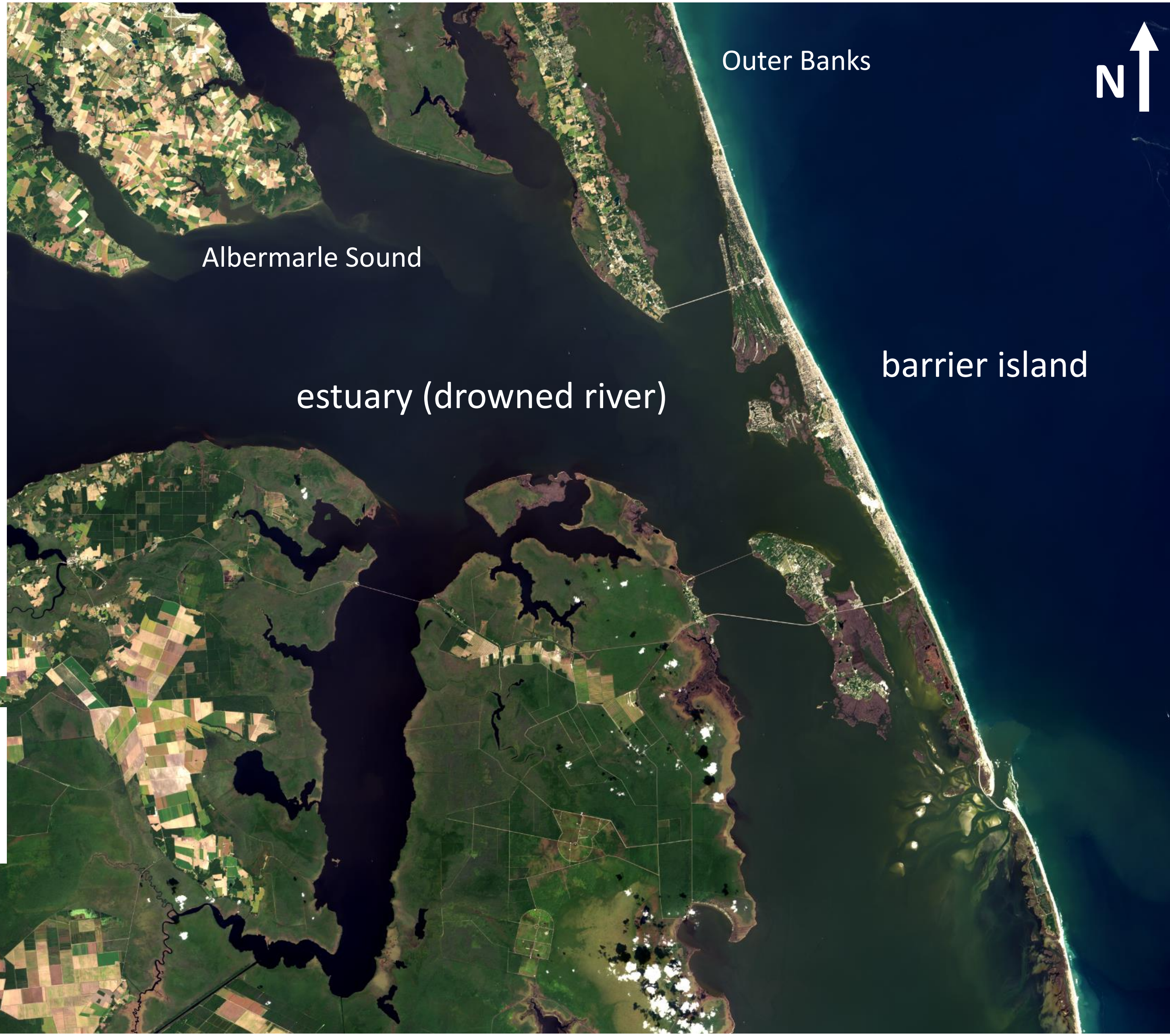
Ridges are a bit like **tree rings**—but not annual

Stable or slowly falling lake level = **strandplains**

Strandplain = collection of beach ridges reflecting lakeward growth

Depositional landform flavor depends on **lake-level trend**



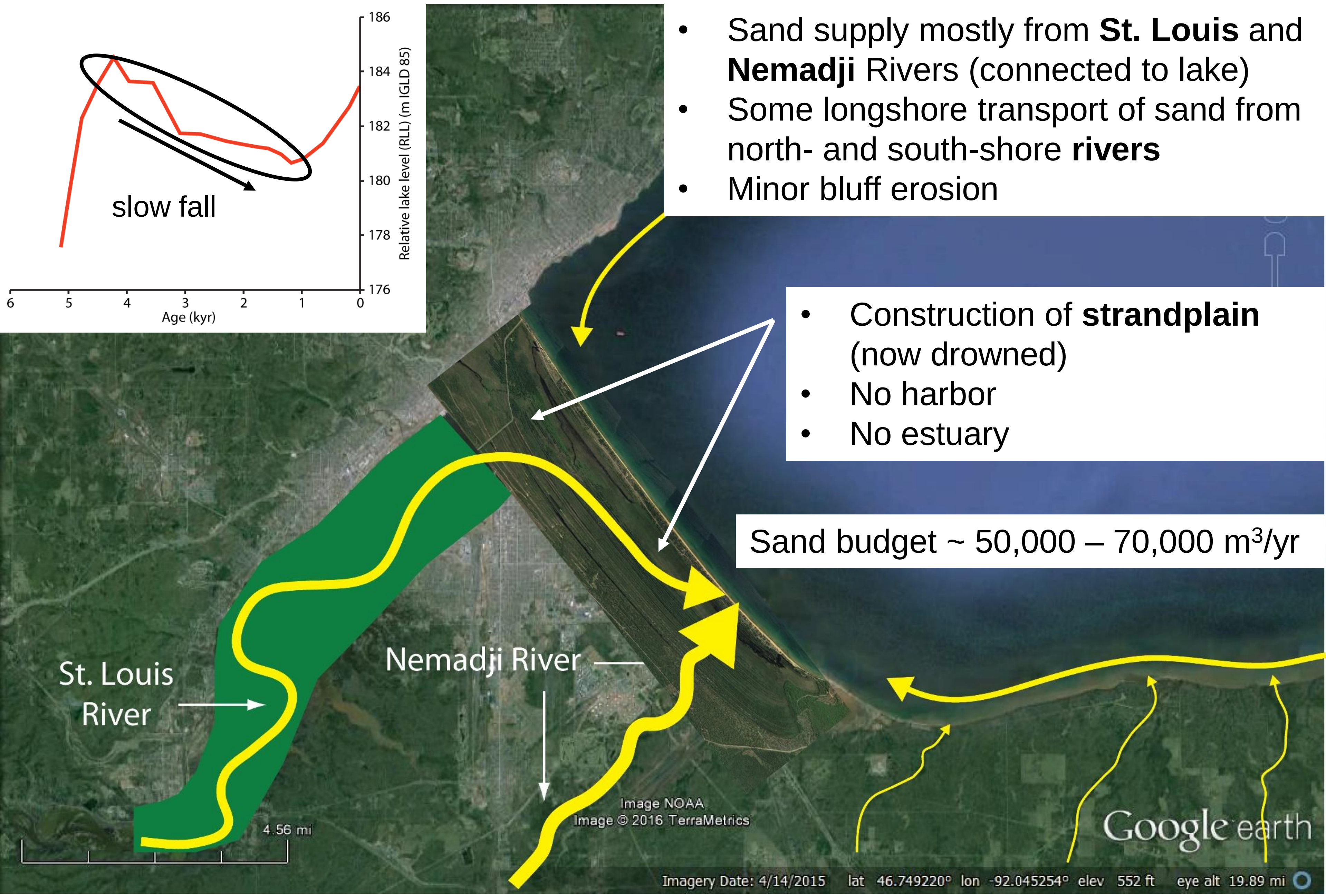


Rapidly rising lake level = **estuaries** and **barrier islands**

Genesis of Duluth Harbor and Minnesota Point

(Genetic model) **4500 – 1200** years BP: Slow lake-level **fall**

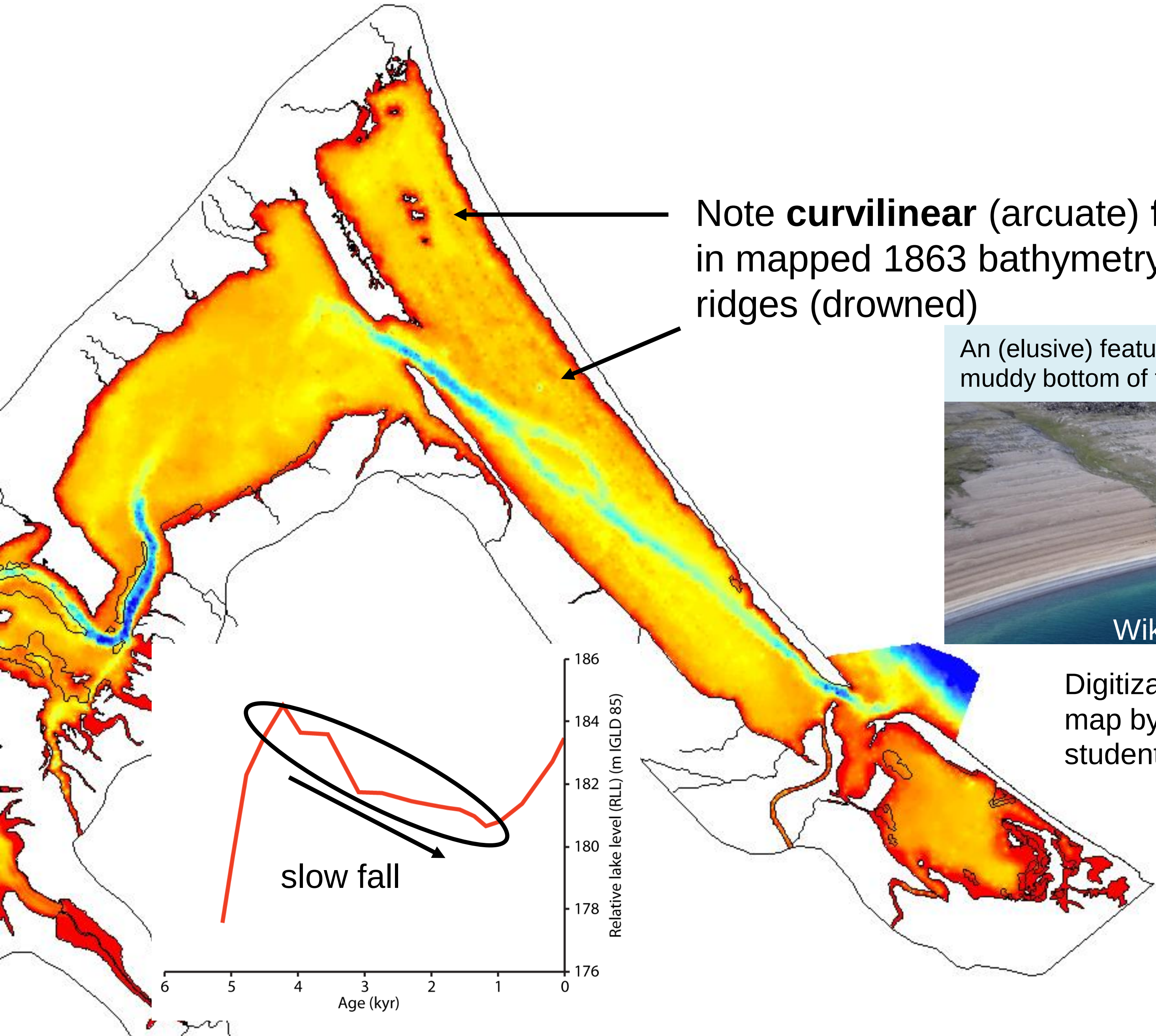
- Sand supply mostly from **St. Louis** and **Nemadji** Rivers (connected to lake)
- Some longshore transport of sand from north- and south-shore **rivers**
- Minor bluff erosion



- Construction of **strandplain** (now drowned)
- No harbor
- No estuary

Sand budget ~ 50,000 – 70,000 m^3/yr

Supporting evidence for **strandplain** beneath harbor



Note **curvilinear** (arcuate) **features** in mapped 1863 bathymetry = beach ridges (drowned)

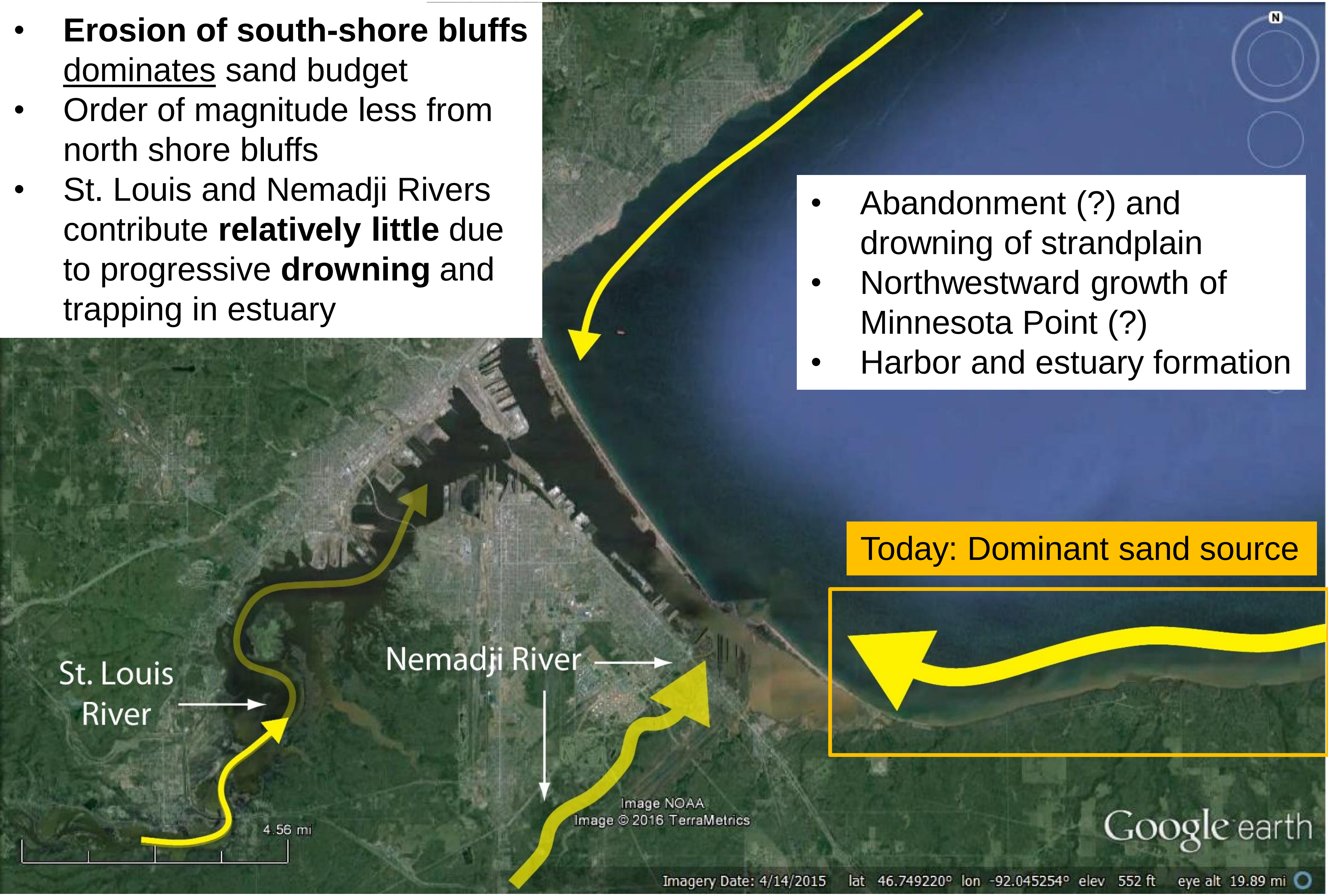
An (elusive) feature like this underlies the muddy bottom of the Duluth / Superior harbor

Digitization of 1863 Hearding map by Andy Breckenridge and students

(Genetic model) **1200** years BP - present: Rapid lake-level **RISE**

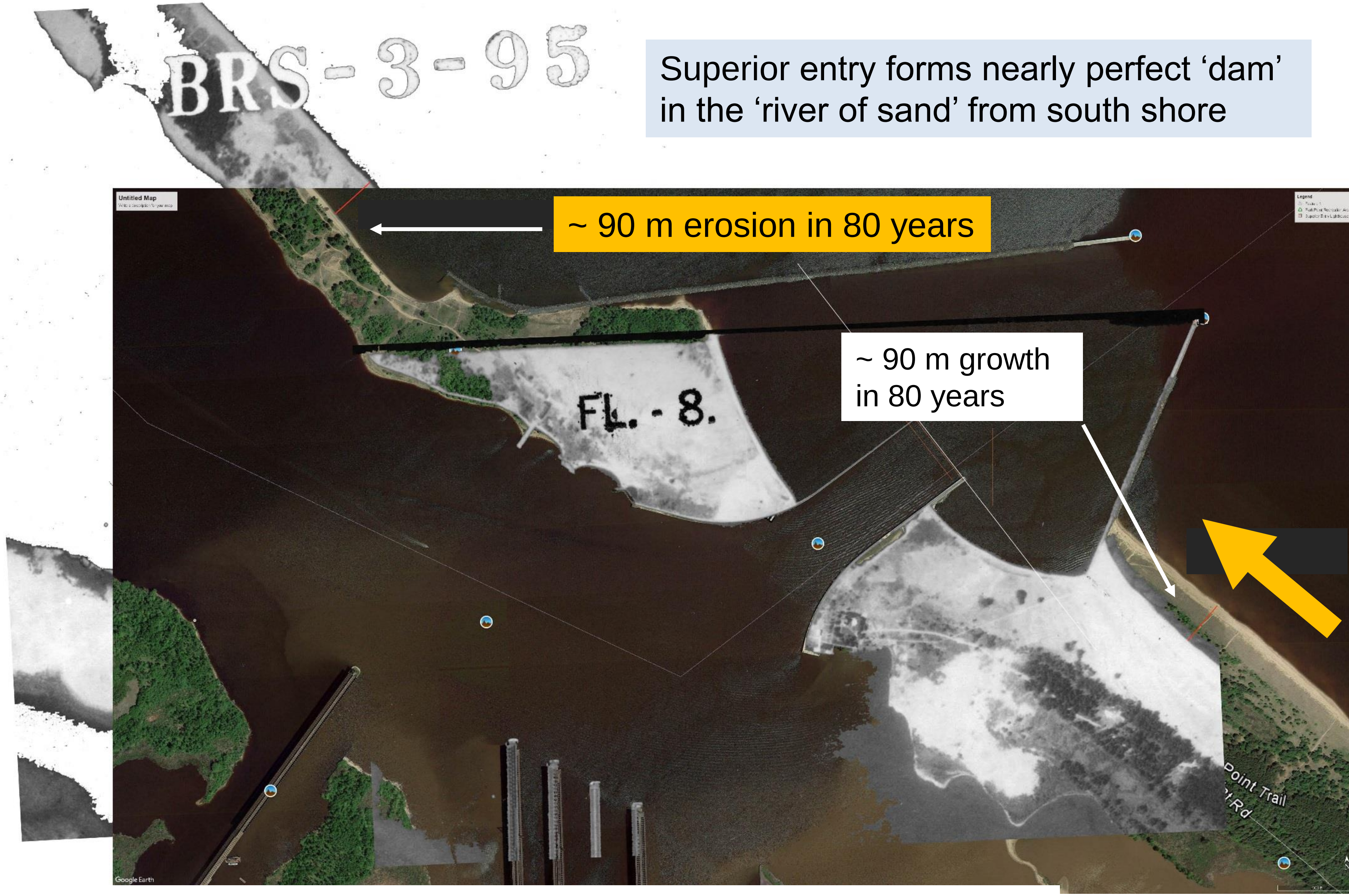
- **Erosion of south-shore bluffs** <u>dominates</u> sand budget
- Order of magnitude less from north shore bluffs
- St. Louis and Nemadji Rivers contribute **relatively little** due to progressive **drowning** and trapping in estuary

- Abandonment (?) and drowning of strandplain
- Northwestward growth of Minnesota Point (?)
- Harbor and estuary formation



The ‘infrastructure’ problem: **Starvation**

Superior entry forms nearly perfect ‘dam’ in the ‘river of sand’ from south shore



Overlay of 2017 (color) satellite image and 1938 aerial photo.

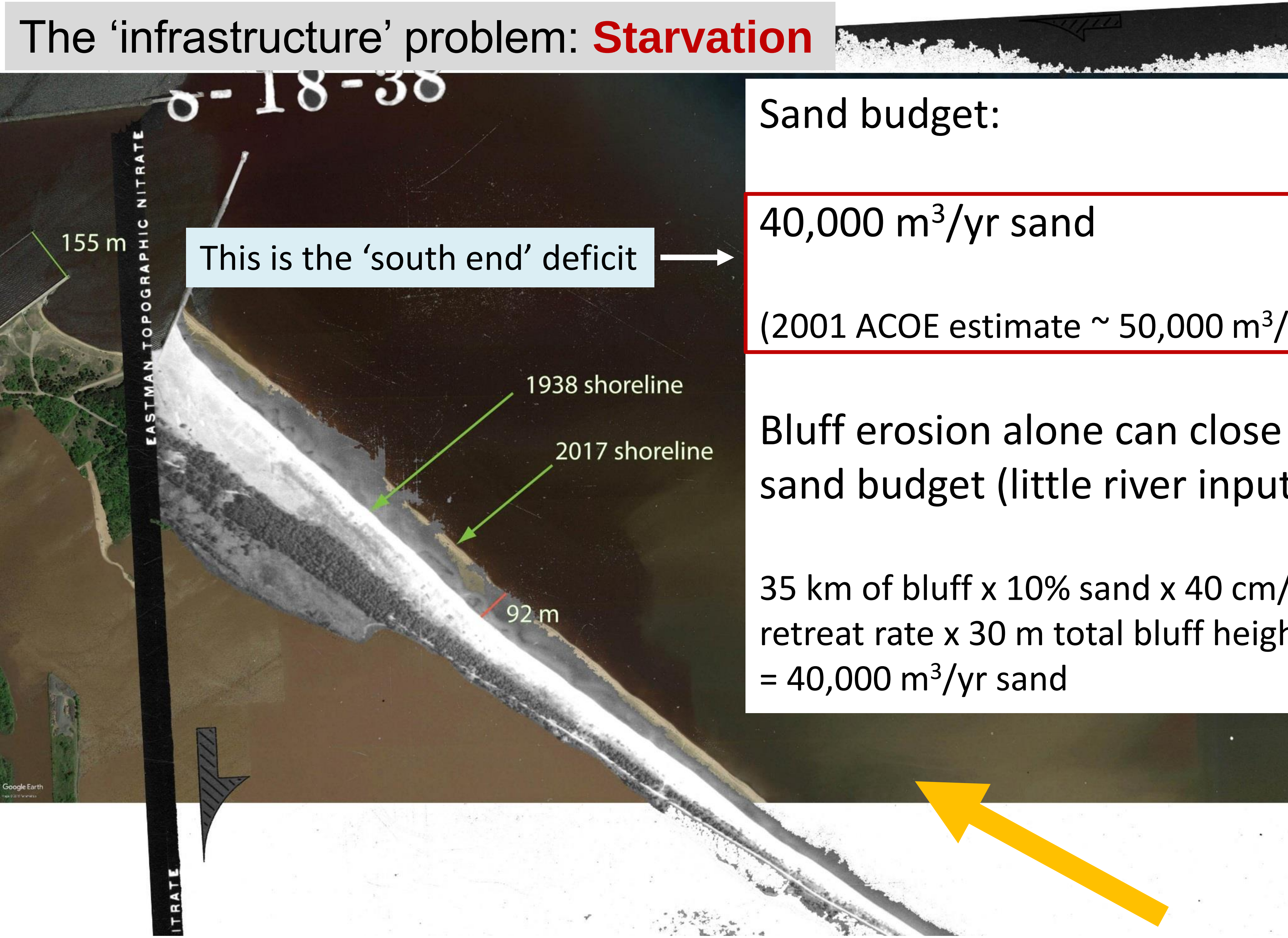
The ‘infrastructure’ problem: Starvation

Similar story with the **Duluth breakwater**

Blocks sediment supply from north-shore bluff erosion

But sediment supply from north shore is significantly smaller

The ‘infrastructure’ problem: **Starvation**



This is the ‘south end’ deficit

Sand budget:

40,000 m^3/yr sand

(2001 ACOE estimate ~ 50,000 m^3/yr)

Bluff erosion alone can close sand budget (little river input):

35 km of bluff x 10% sand x 40 cm/yr retreat rate x 30 m total bluff height = 40,000 m^3/yr sand

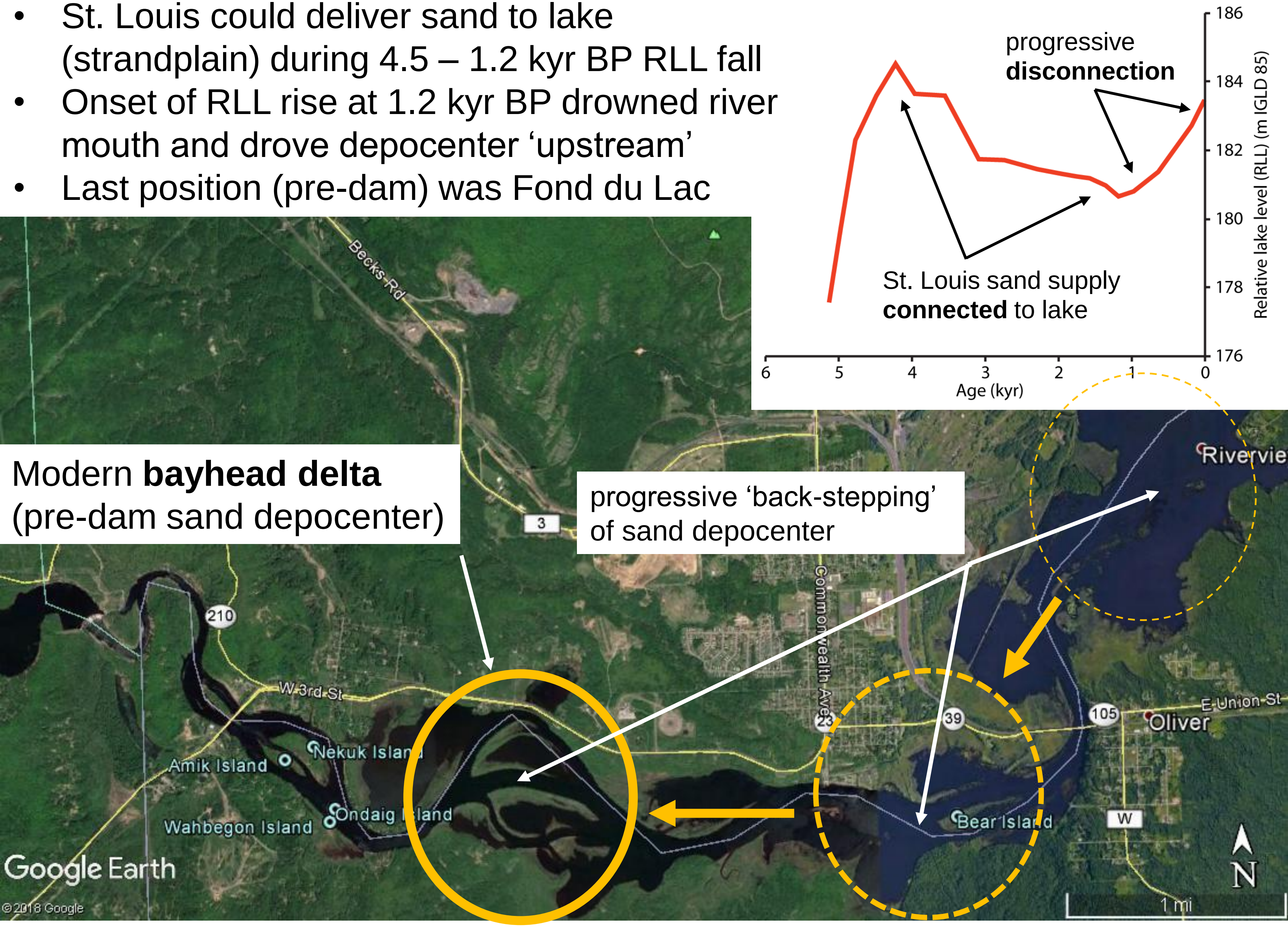
Modern sand sources: What about the **St. Louis River**?

Note progressive drowning of **RELICT** (inactive) **SAND** levees over 160-year timespan

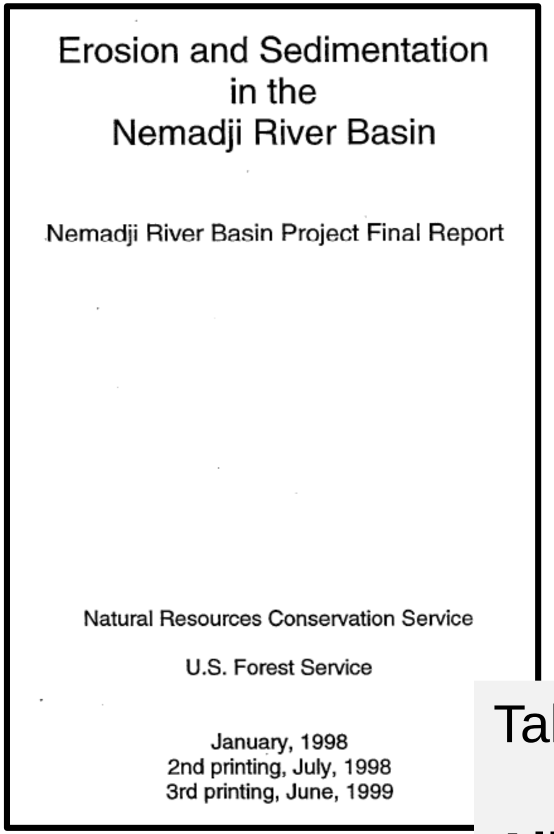
Little sand was reaching Spirit Lake in 1860 (pre-dam era)

Where was it deposited?

- St. Louis could deliver sand to lake (strandplain) during 4.5 – 1.2 kyr BP RLL fall
- Onset of RLL rise at 1.2 kyr BP drowned river mouth and drove depocenter ‘upstream’
- Last position (pre-dam) was Fond du Lac



Modern sand sources: What about the **Nemadji River**?



Erosion and Sedimentation
in the
Nemadji River Basin

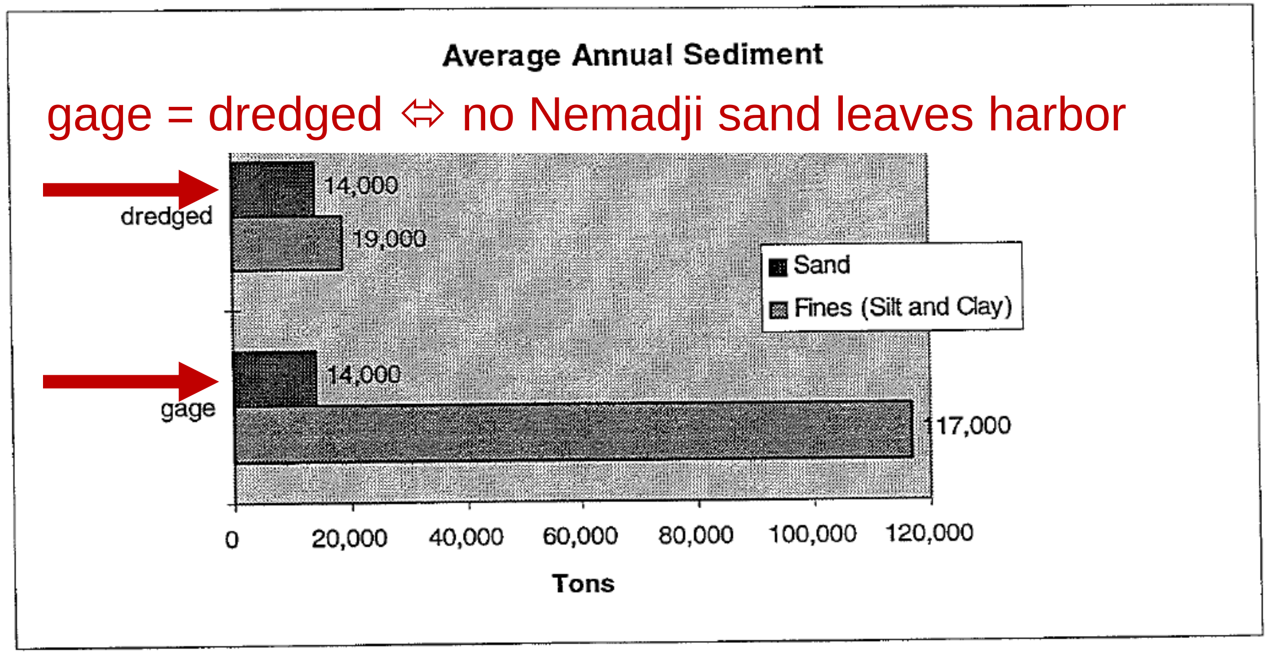
Nemadji River Basin Project Final Report

Natural Resources Conservation Service

U.S. Forest Service

January, 1998
2nd printing, July, 1998
3rd printing, June, 1999

Figure 18: Comparison of Sediment Measured at Gage and Sediment Dredged



Take-home message:

All Nemadji sand trapped in harbor (and then dredged)

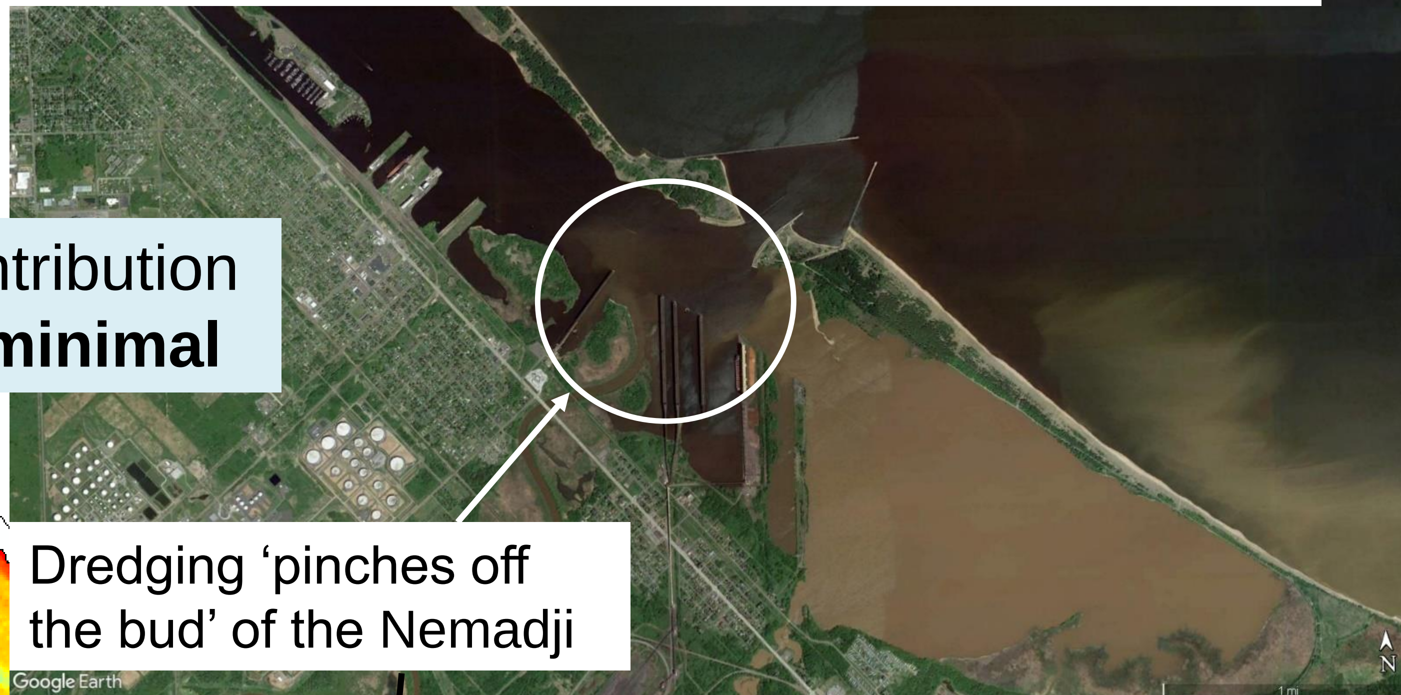
Significant mud transfer to lake (visual confirmation)

14,000 tons/yr ~ 6300 m^3/yr

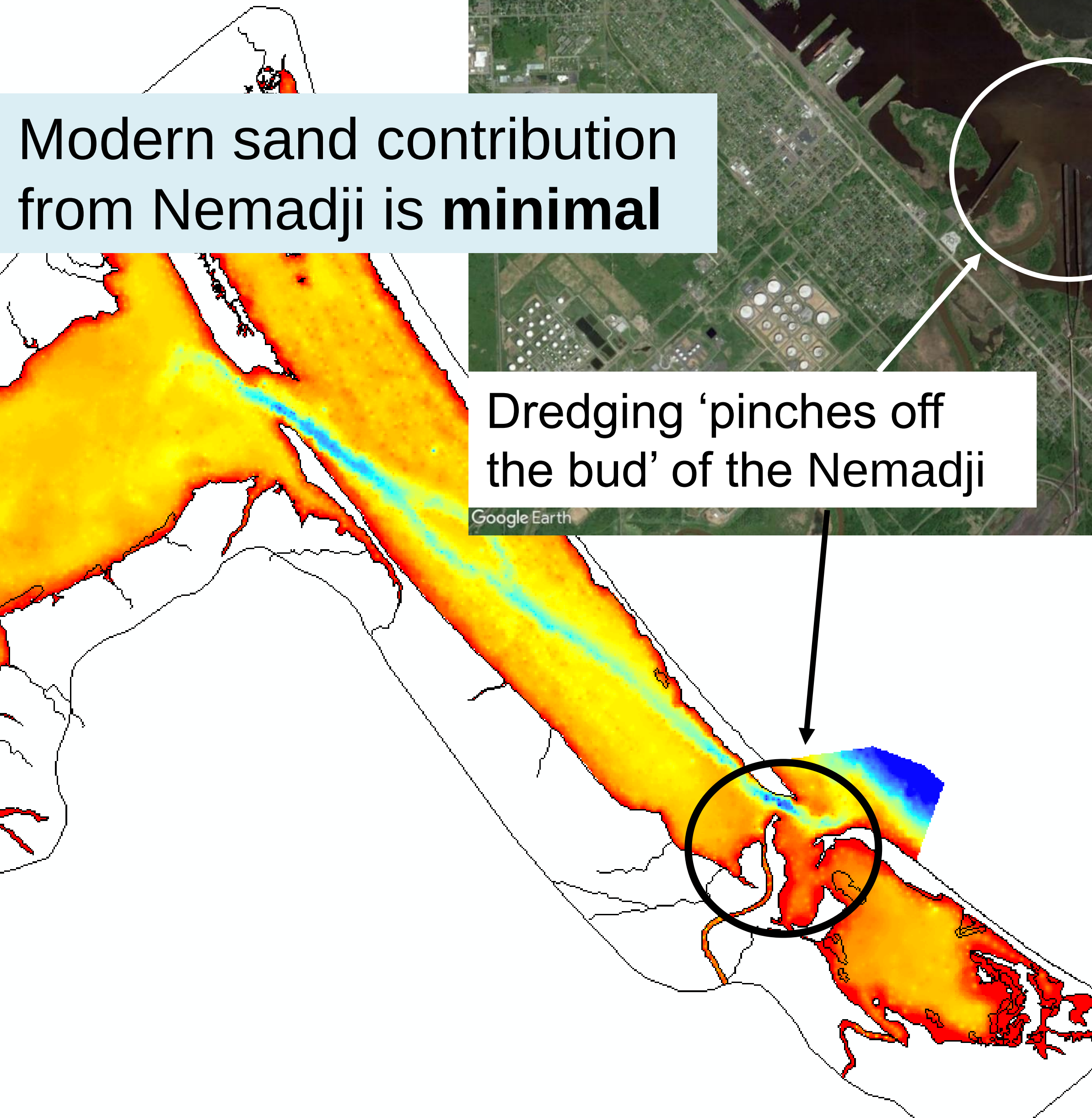
Small fraction of 35,000 – 50,000 m^3/yr needed

Modern sand sources: What about the **Nemadji River**?

Modern sand contribution from Nemadji is **minimal**



Dredging ‘pinches off the bud’ of the Nemadji

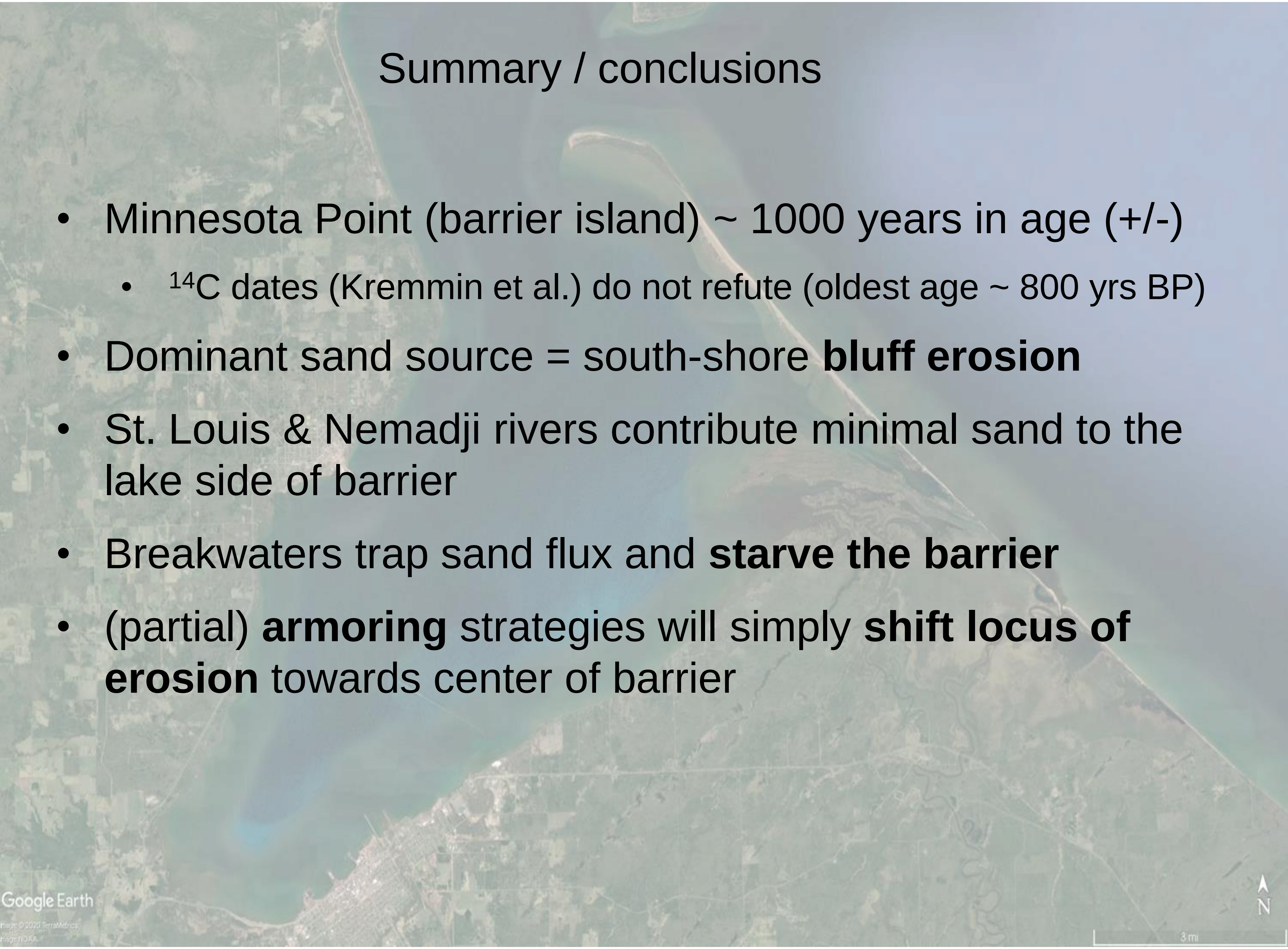


Dredging prevents Nemadji from maintaining **weak connection** to the lake side of the barrier

Note: Nemadji outlet would drown naturally, regardless of dredging activity, albeit at a reduced rate

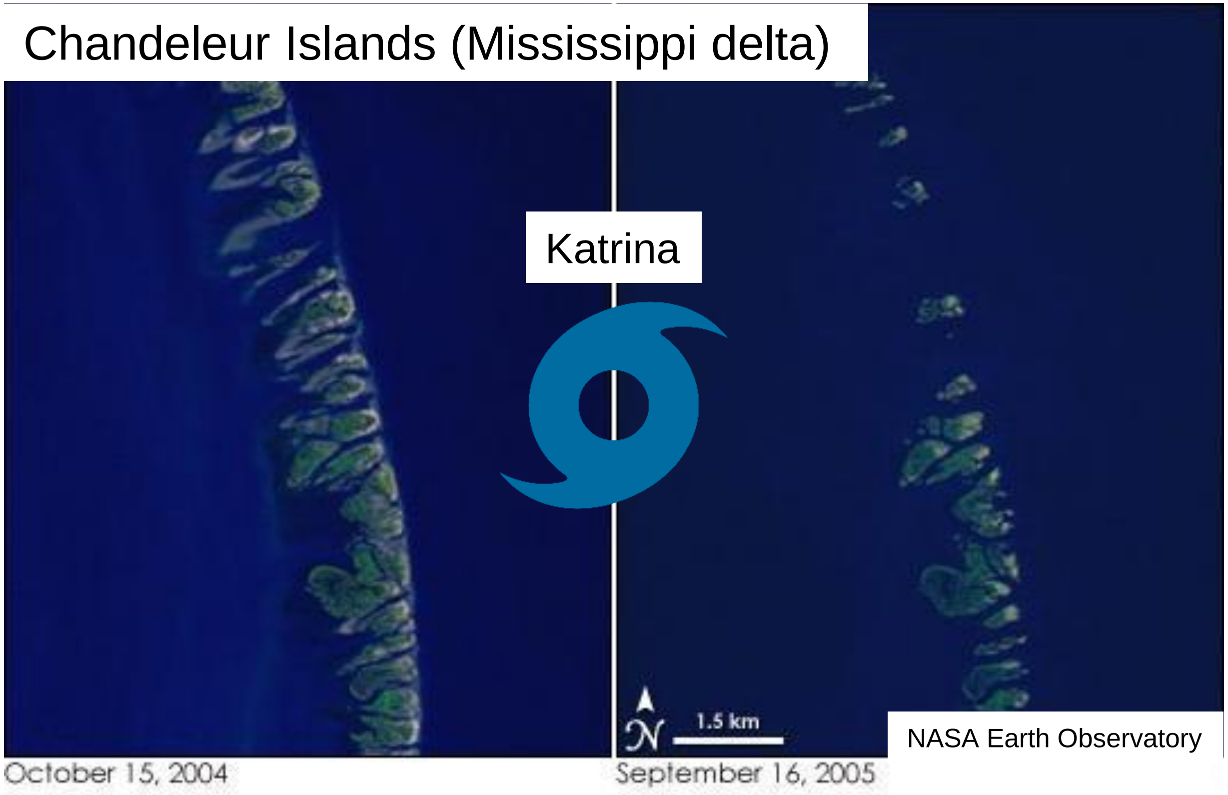
Summary / conclusions

- Minnesota Point (barrier island) ~ 1000 years in age (+/-)
  - ^{14}C dates (Kremmin et al.) do not refute (oldest age ~ 800 yrs BP)
- Dominant sand source = south-shore **bluff erosion**
- St. Louis & Nemadji rivers contribute minimal sand to the lake side of barrier
- Breakwaters trap sand flux and **starve the barrier**
- (partial) **armoring** strategies will simply **shift locus of erosion** towards center of barrier



Final thoughts

For their size, barrier islands are the most **dynamic** / **ephemeral** landforms on Earth



Drowned:
Sea level rise & sediment compaction (subsidence)

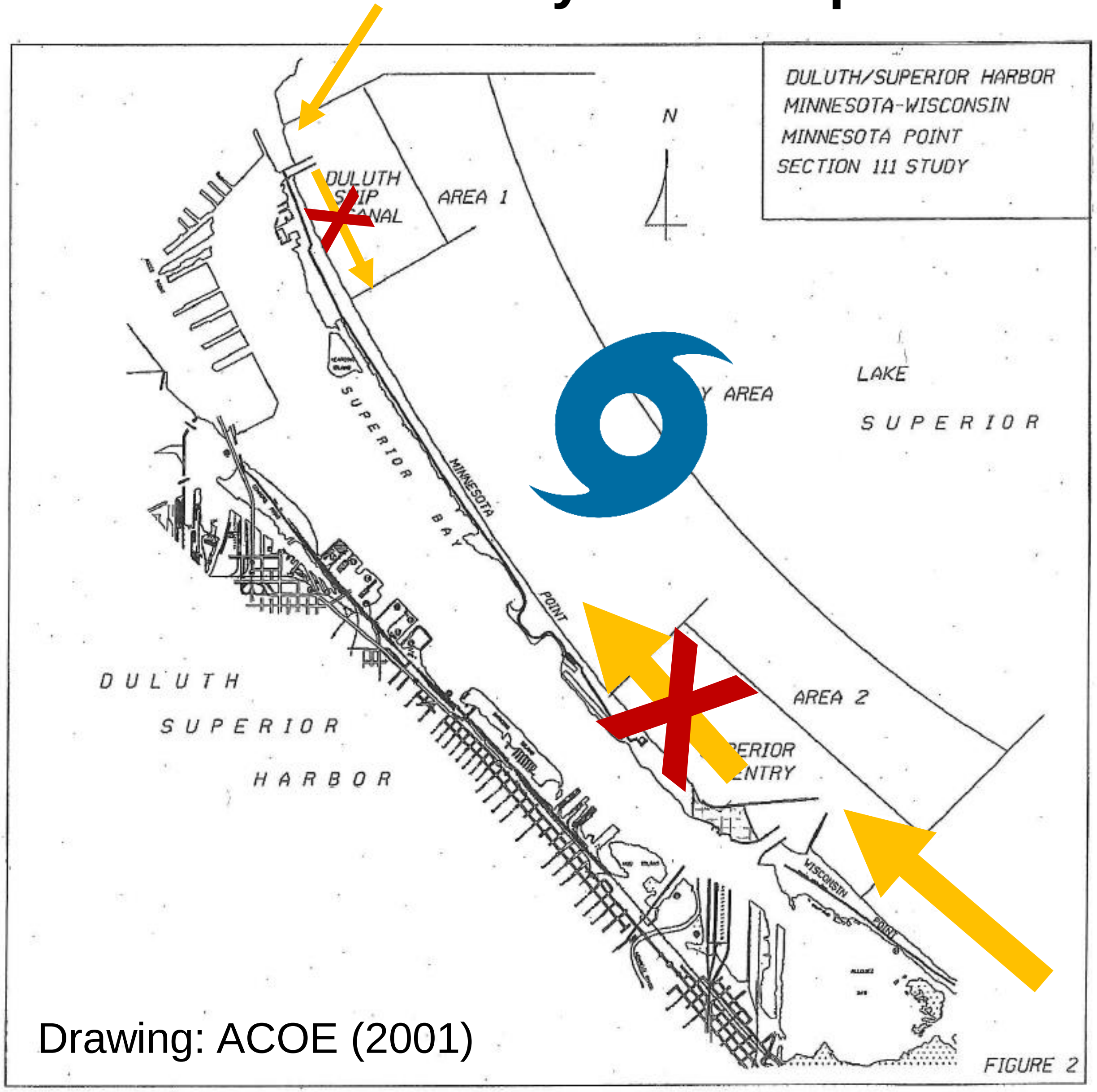
Starved:
Trapping of sand supply behind upstream dams

Battered:
Increasing frequency and magnitude of tropical cyclones

Geologic literature replete with examples of barrier systems reaching ‘**tipping point**’ from which there is no recovery

Final thoughts

For their size, barrier islands are the most **dynamic** / **ephemeral** landforms on Earth



Drawing: ACOE (2001)

Drowned:
Long-term lake level rise

Starved:
Trapping of sand supply behind breakwaters

Battered:
Increasing frequency and magnitude of mid-latitude cyclones

Thanks!

Questions?

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